HAZARDS ANALYSIS

FOR THE

LMMSS TEN FOOT TANK

THERMAL STRATIFICATION AND CRYO-THERMAL CYCLE TEST PROGRAM

AT THE CRYOGENIC PROPELLANT TANK FACILITY (K-SITE)

K022

LOG OF REVISIONS

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1. INTRODUCTION FOR HAZARDS ANALYSIS

This is a hazard analysis for the Thermal Stratification and Cryo-Thermal Cycle Test Program. There are six main areas of hazards associated with this test. They are 1) Liquid Hydrogen Dewar H24, 2) the 10ft. Multilobe Test Tank, 3) VP-5 and the Low Pressure Vent System, 4) the Hydrogen Gas Detection System, 5) the Scaffold System, and 6) the Piping System. As a result of this analysis, several necessary interlocks and safety devices were identified. These can be found on the individual hazard assessment sheets. All hazards identified have a final Risk Assessment Code of 12 or above.

2. TEST DESCRIPTION SUMMARY

Lockhead Martin Michoud Space System (LMMSS) has delivered a 10 ft. tank to NASA Lewis Research Center / Plum Brook Station's Cryogenic Propellant Tank Facility (K-Site) for testing under the direction of NASA Lewis Research Center / Cleveland Office. The 10 ft. tank has an internal volume of 450 cu. ft and is made of a composite material. The test program shall include thermal stratification testing using densified liquid hydrogen and cryo-thermal cyclic testing using NBP liquid hydrogen. The objectives of the stratification tests include the tank thermal stratification potential and the loading, venting, and pressurization characteristics with the tank operating with colder densified propellant. The densified propellant will be formed by pulling vacuum on Dewar H24 using the existing facility Low Pressure Vent System. The thermal cyclic test objectives include demonstration of tank structural performance and demonstration of performance of Reusable Cryogenic Insulation (RCI). Approximately fifty thermal cycles with pressures ranging from 36 psig to 100 psig will be performed.

3. SUPPORTING DOCUMENTS

In addition to the Risk Assessment Sheets, a P & ID and a schematic showing the site layout are included and are identified as Figure 3-1 and Figure 3-2, respectively.

Appendix A is an Explosive Hazards Analysis which looks at the potential explosive energy in the LM Subscale Tank using Document No. NASA CR-134906 on "Workbook for Predicting Pressure Wave and Fragment Effects on Exploding Propellant Tanks and Gas Storage Vessels." This study basically shows that the K-Site Control Room at a distance of 690 ft. from the test stand is safe for pressure waves and fragments and does not alter the existing K-Site Explosion Analysis.

Appendix B provides a general design summary of the LM Subscale Tank. It provides a summary of the structural analysis performed on the tank and shows a minimum safety factor of 1.15 when compared to allowable stress limits for the tank components.

4. EQUIPMENT DESCRIPTION

4.1 10 Ft. Multilobe Test Tank

The Lockheed Martin Manned Space Systems (LMMSS) 10 Foot Multilobe Composite LH2 Tank (Multilobe Tank) was tested at the John C. Stennis Space Center in support of the X33/RLV, Phase 2 Program and is now being tested at NASA's Plum Brook Station. The composite tank is a test bed for a number of key X-33/RLV enabling technology demonstrations. The test data generated has verified several breakthrough technologies key to the success of large composite tankage for X33, RLV, and any future launch vehicles.

Single Stage to Orbit (SSTO) vehicle mass fraction requirements dictate tankage weights that can only be achieved through use of advanced composite materials. In addition, the X33/RLV lifting body vehicle shape mandates non-cylindrical tankage. A multilobe tank configuration was chosen for X33 to maintain weight efficient circular cross sections while meeting vehicle shape requirements.

Testing of the Multilobe Tank, at the Stennis Space Center, High Heat Flux Facility (HHFF) located in Mississippi, and at NASA's Plum Brook Station, K-Site Facility in Sandusky, Ohio, consists of filling the tank with liquid hydrogen, and pressurizing to achieve X33/RLV flight pressures and strains (cryogenic cycling). The test setup allows for stringent monitoring of tank performance with respect to structural integrity, cryoinsulation, and LH2 containment through strain gauges and temperature instrumentation systems. To date, 30 cryogenic pressure cycles and 32 ambient pressure cycles have been achieved demonstrating large-scale composite multilobe tankage.

A mechanically joined multilobe demo tank design was developed to demonstrate RLV technology on a geometrically scaled tank using full size details, equivalent strains, and equivalent materials and processes. The demo Multilobe Tank configuration consists of two 5-foot diameter, 17 foot long cylindrical lobes mechanically joined at a 10 degree angle. The basic overall structure is shown on Figure 4.1-1. Fiber placement was selected as the baseline fabrication method to support automated fabrication of large-scale tanks.

IM7/977-2 graphite/epoxy was selected as the material based on the extensive cryogenic database generated during NASP. The design pressures were scaled up to obtain equivalent strains in the full size details. Testing was baselined as a pressurized/liquid hydrogen test with fill and drain rates representative of X33/RLV.

The current X33 composite hydrogen tank design configuration consists of a four lobe composite tank with bonded Y joints. The Multilobe Tank Test Article is approximately ½ the scale of X33 tankage and demonstrates large scale composite tankage technology including the materials, adhesives, processes, joints, reusable insulation materials and processes, the vehicle health monitoring sensors, and candidate repair methods planned for use on X33 and ultimately RLV.

The tank was designed and analyzed for the ultimate pressure of 147 PSIG. The previous test results correlated well with analytical predictions. Figure 4.1-2 shows a table with factors of safety calculated for the various components. The current test plans for testing at Plum Brook were with tank test pressures of 35 PSIG, 75 PSIG, and a maximum of 100 PSIG. These test pressures are the same as those used at Stennis.

4.2 Liquid Hydrogen Dewar H24

Liquid Hydrogen Dewar H24 has a capacity of 13,000 gal. with super insulation (foil and glass paper wrap) inside a vacuum jacket. It has a working pressure of 100 PSIG and is equipped with extensive instrumentation, much of which can be read out at a remote location. Instrumentation includes pressure and vacuum gages. All liquid connections are CVI style bayonets.

The remotely operated valves include the supply valve, return valve, and vent valve, and are pneumatically actuated by solenoid valves. The Dewar also has hand operated valves. This dewar has a pressure building heat exchanger equipped with an automatic pressure control loop.

The Dewar will have a critical role in the Thermal Stratification Tests using densified hydrogen. During this phase of testing, vacuum will be pulled on the product in the dewar using VP-5 of the K-Site Low Pressure Vent Vacuum System. Once the Dewar has been densified to a pressure of 1.75 to 2.0 PSIG, a mixture of GH2 and GHe will be used to pressurize the dewar above atmospheric pressure for liquid transfer to the tank.

Since the Dewar is not designed to permit pulling vacuum on the product, several steps were taken to eliminate the possibility of pulling air into the dewar. They are listed below:

1) A tent will be installed around the valve-house to allow GHe pressure purging of all mechanical joints. A pressure switch will alarm in the Control Room when the required purge pressure is lost. If this occurs, vacuum operations will stop.

2) A remote readout will be provided in the Control Room for indication of the Dewar's main vacuum jacket pressure. A rapid rise of the jacket would mandate the repressurization of the product tank to prevent damage to the inner tank.

3) The pressure building coil is not vacuum jacketed and therefore will be valved off and isolated during the Densification Tests. As stated earlier, pressurization of the product will be achieved with GHe and GH2 using the facility control valve ROV-2109.

4) The Dewar has been verified to be capable of vacuum operations by performing leak tests under a no-detectable leak criteria. Burst discs and relief valves have been verified to work under vacuum conditions also. Results of this leak check are in Appendix C.

5) During vacuum operations with VP-5, a continuous GHe purge will be maintained on the Dewar vent and mechanical flanges. Pressure transducer 2319 will provide an alarm warning when the pressure downstream of the Dewar vent valve is negative (i.e. under vacuum). This transducer is outside the vacuum envelope and should never be below atmospheric pressure.

4.3 Gas Detection System and Equipment Trailer

There are several areas on the Multilobe Tank that are critical for determining hydrogen leakage. These particular areas are monitored with a Hazardous Gas Detection System which uses a Turbo Mass Spectrometer (TMS) as the heart of the entire system. Two other components of the system are the Sample Delivery System and the Data Acquisition/Control System.

The mass spectrometer used is the Orbital Science Corporation (OSC) MGA 1200 fixed collector, magnetic sector. The MGA 1200 uses a heated bypass inlet for introducing the samples into the mass spectrometer. The MGA is equipped with two inlets, one active at a time. Five gases [hydrogen (H_2), helium (He), nitrogen (N_2), oxygen (O_2), and argon (Ar)] can be monitored in real time. The ability to simultaneously monitor five gases is accomplished by using separate collectors to obtain the ion current for each gas. The ion currents are then converted to voltages by discrete electrometer cards. The outputs of the electrometer cards are then fed into a data acquisition control unit for communication with the control computer. This particular test program will be looking for hydrogen. The TMS control software is written in labview. The software also enables data archiving.

The gas flow through the sample delivery system (SDS) is depicted in Figures 4.3-1 and 4.3-2. It is important to note that the figure does not include the add-on port which adds an additional eight lines. The SDS, without add-on, has inputs for six calibration gases and eight sample lines. The flows of the calibration gases are controlled by mass flow controller MFC1 while the flows of the sample lines are controlled by MFC2. In addition the sample lines use a pressure transducer to monitor the pressure of the lines. A GAST brand diaphragm pump is used to draw the samples past the mass spectrometer inlet. The SDS uses 14 Marotta brand 3-way valves to control the selection of the line to monitor. In the case of this application at K-Site, five different bagged zones on the tank will be monitored by flowing a variable rate of gaseous nitrogen through the bag and out to the SDS.

The data acquisition/control system is composed of a local data acquisition unit and a remote computer located in the K-Site Control Room. The data acquisition unit contains sub-units for analog-to-digital conversion, and digital control lines. The data acquisition unit can be viewed as the interface between the mass spectrometer, sample delivery system, and the computer. The computer can be either a personal computer or a Macintosh computer. The screens and overall operation of the software will be the same for either computer.

The data acquisition/control subsystem uses a HP 3497A data acquisition/control unit to monitor analog voltages and to select the desired valves. The HP 3497A is a control unit with an optional high-precision scanning digital voltmeter (DVM).

The HP 3497A is the link that connects the control computer to the SDS and mass spectrometer. The HP 3497A receives all the commands sent from the computer and enables the correct action to occur in the system. Likewise all monitored voltages are converted to digital signals and transferred to the computer via the HP 3497A.

The TMS, the SDS, and the Computer Controller are contained in an Equipment Trailer. The 8 ft. x 16 ft. trailer will contain these components for the Gas Detection System plus the signal conditioners for the 200+ strain gauges on the 10ft Multilobe Tank. Neither of these two items are rated for Class I, Group B, Division 2 locations (hydrogen assumed normally not present but may occur at times from leakage). The trailer will have a door and several windows. The location of the test tank relative to the trailer has been set at 30 ft. This distance is consistent with the location used at Stennis and is critical to maintain consistent data between the two test programs. In addition to the two main electrical elements mentioned above, there is an electrical cabinet with a shunt trip breaker, an air conditioner (critical to maintain a specified temperature in the trailer), and a Neff for data transmission. Two GH2 sensors and one O2 sensor are included in the trailer for constant gas monitoring.

As a result of the electrical classification of the components in the trailer and the distance of the trailer from the hydrogen tank, several significant safety measures are taken to eliminate the potential of an ignition of a hydrogen gas/air mixture in a confined space. They are:

1) There will be two pairs of GH2 detectors located at the top of the test stand and inside the trailer. Warning will be provided at 0.5% GH2 and all power will be terminated to the trailer at 1% GH2. This will be achieved by a shunt trip breaker located in a purged electrical box in the trailer. Also, to eliminate the source of the GH2, the tank vent valves will be opened to eliminate tank pressure.

2) The air conditioner does not have an air intake associated with it. All cooling is performed on the air inside the trailer without any outside air as makeup or exchange.

3) The main gas lines to the trailer (500 L/Min) will be routed outside the trailer with only the small intake lines for the gas analyzer (5 L/Min) routed inside the trailer. All gas lines will be bubble leak checked to ensure system integrity.

4) The Calibration bottles for the Gas Analyzer will be located outside the trailer.

5) A manual power shut-off for the trailer will be provided in the Control Room.

4.4 Low Pressure – Vent System

An electrically powered heat exchanger is used to warm cold hydrogen gas before it enters the vacuum pump. A temperature controller is installed on the heat exchanger to maintain the outlet gas temperature between $40^{\forall}$ and $100^{\forall}$ F. High and low temperature alarms downstream of the heat exchanger alarm if the GH2 temperature is outside this range.

A KT-850 vacuum pump is located downstream of the heat exchanger. The pump is GN2 gas ballasted. The pump motor is a totally enclosed fan cooled type motor and is suitable for use in a Class 1, Division 2, Group B environment. The GH2 which is exhausted from the pump is vented through a heat exchanger that cools it from $130^{\forall}$F to approximately $110^{\forall}$F by using the facility raw water system.

An 02 detector is located on the downstream side of the vacuum pump. The detector will sound a warning alarm if 0.5% 02 has infiltrated the vacuum system. A shutdown of the Low Pressure Vent System occurs at 1% 02 or 25% of the Upper Flammable Limit (UFL).

For this test program, the Low Pressure Vent System will be used to establish densified hydrogen in Dewar H24.

4.5 Scaffold System

The 10-ft. tank is serviced over the entire height on its two long sides by using a scaffold system. Two 3-pt wide planks, one on either side, are bolted together with one common support framework. The support framework slides up and down inside the inner support structure for the 10 ft. tank to permit access to various tank elevations. Once moved, a permanent ladder provides vertical access to the scaffold at any of its elevations. The platform is secured at these elevations by spring retracted pins. There are a total of four pins, one at each corner of the framework. Each plank is provided with toe plates and handrails. Each side of the platform has been load tested to 800 LBS.

4.6 Piping System

The 10-ft. Multilobe Tank is supplied with liquid hydrogen by two vacuum jacketed 1.5” lines, one to each of the tank bottom lobes. Each of these lines has a control valve. Valve ROV-2302 is a PHPK vacuum jacketed variable control valve and valve ROV-2303 is a PHPK vacuum jacketed discrete valve (open/close). Each of the two lobes also has a 2” vent line. One of the vent lines is a 2” mechanically insulated line and is used as a drain line for routing the liquid back to Liquid Hydrogen Dewar H25. The other 2” vent line is branched out into three 1.5” non-insulated lines. Two of these lines are routed through 1.5” remote activated valves to the South hydrogen burn-off. The other 1.5” line is for a back pressure control valve to maintain pressure in the 10ft. Multilobe Tank. A vacuum rated burst disc and a gas pressurization line are also tied into this system. The two liquid supply valves, the one liquid drain, and the gas pressurization valve are normally closed valves. The two vent valves are normally open. Relief valves are provided between valves in the event where liquid could be trapped between closed valves.

5. OPERATIONS

5.1 General

The 10 ft. Multilobe Tank stands vertically in its support structure. It rests on and is bolted to a flat stainless steel table. The top of the tank is supported by guide wires to carry wind loads. Access to the two major sides of the tank is obtained by the Scaffold System. The Scaffold System can be moved up and down the entire height of the tank and is specifically supported at five different elevations. The top of the support stand is equipped with two gaseous hydrogen detectors.

The tank consists of two 5 ft. diameter lobes joined at the center with a support plate. The two lobes are capable of communicating with one another through holes provided in this center support plate. Each lobe is equipped with a 1½ “ bottom supply line and a 2” vent line. Both bottom supply lines are vacuum jacketed and are configured to receive liquid hydrogen from Dewars H24 or H25. One of the vent lines is used as a drain or return line for liquid hydrogen going back to Dewar H25. The other vent line is configured with a direct vent line to the K-Site south burn-off, a burst disc, and a variable controlled back pressure control valve. External pressurization can be achieved using GHe or GH2 using a programmable control valve.

The tank is equipped with a vast array of instrumentation. There are approximately 50 thermocouples, 225 strain gauges, and 60 silicon diodes. The tank is equipped with a capacitance probe made by B.F. Goodrich. The probe will be used to control the flow rate of the supply liquid and the amount going out the drain line. There is one flow transmitter for monitoring the liquid going to the tank. The data system will be recording pressures from five transducers directly associated with the tank and approximately 25 other facility related transducers. All of the required signal conditioners are located in the equipment trailer.

A boil-off pressurization system will also be included in the vent piping configuration. An orifice plate, differential pressure transducers and a thermocouple are installed to provide needed data on the tank boil-off rate.

In addition to obtaining data on the liquid flow characteristics of the tank, an additional purpose of this test program is to obtain data on tank leakage. Using a material identified as IM7/977-2 Graphite/Epoxy, Leak-Rate Data is being obtained on the critical joints as well as monitoring the leak rate in one section of the wall material by itself. The critical joints are the two vertical seams of the two lobes and the two bottom, cold molded joints for each of the bottom covers including the transition of the wall material to the stainless steel penetrations and reinforcing plates. This makes a total of five areas including the one area of the wall, being monitored for hydrogen leakage. Each particular area is bagged with a fiber-reinforced polyethylene material. Each bag is supplied with a variable controlled, gaseous nitrogen purge. The flow rate into each bag is adjusted to combine with whatever hydrogen leakage is present to equal a total flow rate of 500 L/M coming out of the bag.

This gas is then routed from the tank through 1” reinforced tygon tubing to the equipment trailer which houses the Gas Detection System. As explained earlier, a small portion of the gas is pulled into the Turbo Mass Spectrometer for analysis while the remaining gas is sent to the south hydrogen burn-off.

5.2 Thermal-Cyclic Test Program

As stated earlier, the tank was originally tested for thirty cryo-thermal cycles at the Stennis Space Center. These cycles were performed at pressures of 36 psig, 75 psig, and 100 psig. Fifty additional thermal cycles are now to be performed at K-Site, with a potential of performing twenty more cycles if these are successful.

The test pressures of 36, 75, and 100 psi represent the following:

36 psi	• RLV/X33 operating pressure
75 psi	• Pressure required to achieve typical X33 LH2 tank equivalent strains at operating pressure
100 psi	• Multilobe Tank Test Article limit pressure • Pressure required to achieve typical X33 LH2 tank equivalent strains at ultimate pressure

The objective of this test program is to demonstrate the performance of large scale composite tankage and the associated enabling technologies under cyrogenic/pressure cycling conditions in support of X33/RLV mission requirements. Specifically the test objectives are to:

1) Demonstrate scale up of fiberplaced composite tankage by testing a one-quarter scale RLV liquid hydrogen multilobe tank;

2) Verify the test article’s ability to contain liquid hydrogen at operating pressure, after cryogenic and mechanical cycling;

3) Monitor permeation as a function of cryogenic and mechanical cycling

4) Evaluate the performance of the lobe joint / mechanical seal configuration under cryogenic and mechanical cycles;

5) Evaluate bonded joints with respect to strength and leakage under cryogenic and mechanical cycles;

6) Evaluate dome access port integration configuration with respect to strength and leakage under cryogenic and mechanical cycles;

7) Evaluate strain gage installation procedure for use on X33;

8) Evaluate X33/RLV candidate reusable cryogenic insulation systems under cryogenic and mechanical cycles;

9) Evaluate X33/RLV candidate permeation repair methods under cryogenic and mechanical cycles;

10) Verify the analysis methodology through correlation of pretest analytical predictions with test data.

Primary test loading conditions on the Multilobe Tank consist of internal pressure and cryogenic load cycles. This test will perform approximately fifteen cryogenic cycles on the Multilobe Tank at each of the three pressures specified earlier.

A 5 psig GHe bubble leak check and an ambient proof test will be conducted prior to each pressure level increase. The proof tests will be conducted using ambient GHe for each pressure level. An ambient GH2 leak check test will be performed after the GHe Proof for each pressure level using the Gas Detection System or pressure decay test.

A 5 psi ambient GH2 test will be conducted each day prior to testing to verify tank/ facility integrity. A hold will be maintained, at 5 psi., long enough to take leak detection readings from each of the five bagged zones.

After the brief GH2 Leak check, the tank will be filled with liquid hydrogen. It will then be pressurized at the desired pressure and held for approximately 15 minutes. The liquid will be drained back to either dewar as directed by the test conductor. Once drained a low flow rate at 5 psig followed by a high flow rate at 10 psig will be used to warm up the tank to 30^{B}F. At this time the tank will be ready for the next test cycle. It is currently planned that one cycle will be performed per day with approximately four per week. At the end of every four to five cycles, or before a new higher pressure range, a GHe bubble leak check at 5 psig will be performed.

A LMMSS Test Representative shall be present during testing. Authority to proceed to the next load level or cycle will be given by the LMMSS Test Representative. Any deviations from the baseline procedure shall be mutually agreed upon by the LMMSS Test Representative and the Test Conductor.

5.3 Thermal Stratification Test Program

The Thermal Stratification Test Program will use densified liquid hydrogen to study the flow characteristics and stratification of LH2 in the 10 ft. Multilobe Tank. Densified liquid hydrogen will be made in the K-Site Liquid Hydrogen Dewar H24. The dewar was leak checked to a no-acceptable leak condition. As an additional safety measure, all mechanical joints in the valve house of the dewar will be bagged and purged with GHe. During the production of the densified propellant, a pressure switch in the valve house will confirm the constant purge. The pressurization coil of the dewar will be valved off to eliminate a potential major leak source. Gaseous hydrogen and gaseous helium pressurization of the dewar will be achieved through an external source. Valve ROV-2109, with a Moore Controller, can provide to the dewar the capability of using either gas and it is also possible to chill the gas using the facility’s small heat exchanger. The GH2 or GHe enters the tube bundle in the heat exchanger at the top and exits at the bottom. The tube bundle sits in a bath of LN2 and the liquid level is controlled by a temperature controller which senses the gas temperature at the nitrogen vent line. The heat exchanger can achieve variable temperatures depending upon the required flow rate.

The dewar has been connected to the facility Low Pressure Vent System which will provide the capability of pulling vacuum on the dewar. The Low Pressure Vent System uses a Kinney KT-850 Mechanical Vacuum Pump to pull vacuum on liquid hydrogen tanks. To ensure the safety of the system, a Servomex Oxygen Analyzer constantly monitors the discharge gas of the vacuum pump verifying the absence of oxygen in the system. It should be noted, that this detection system will not detect the presence of oxygen in the dewar since it will condense into solid or frozen ice. For this reason, immediately at the end of this phase of testing, the dewar will be drained and vacuum purged twice with GHe to remove all hydrogen before the solid oxygen vaporizes back into gas. The dewar will then be moved to an off-site location. After the dewar has completely warmed up and before its next use it will be purged again with GHe.

The sequence of steps to be followed during testing will first begin with the production of densified liquid hydrogen in Dewar H24. The Multilobe Tank will then be filled with normal boiling point liquid hydrogen from K-Site's second dewar, H25. Densified liquid hydrogen will be brought into the bottom of the tank while liquid at the top of the tank is being drained back to Dewar H25. The tank will be maintained under constant pressure while the capacitance probe controls the supply and drain valves to maintain a constant liquid level. Tank pressures during these tests will not exceed 35 psia. Variable flow rates will be used while monitoring the stratification of the liquid in the tank. A five day test period is planned for this phase.

5.4 Test Sequence

The test sequence begins with approximately one week of the Thermal Cyclic Tests. This will establish a baseline for the tank and to confirm the results of previous testing done at Stennis. The second week of testing will center on the Thermal Stratification Tests. This week of testing will be performed with 24 hours around-the-clock operations to accommodate the production periods of the densified propellant and to provide constant surveillance of systems during this process. After this, the Thermal Cyclic Test Program will continue with single shift operations and a goal of four cycles per week until all cycles are completed.

5.5 Interlocks For The Multilobe Tank Tests

The interlocks for the 10ft. Multilobe Tank Tests are listed below:

1) Valve ROV-2105 cannot be opened unless valves ROV-265 and ROV-2902 are closed and ROV's 265 & 2902 cannot be opened unless ROV-2105 is closed.

2) Pressure transducer PT 2319 monitors pressure between ROV-2402 and CV-2313. A low presure alarm is triggered at 14.2 PSIA.

3) Pressure transducer on tank causes alarm and vent valves ROV-2307 and 2308 to open on the 10-ft. Multilobe Tank. It will also close ROV-2304 (pressurization valve).

4) Pressure switch alarms on purged cabinets loss of pressure.

5) GH2 detection at support trailer and support structure alarm at 0.5% GH2 (warning) and shutdown power to trailer systems at 1% GH2. Also at 1% GH2 the tank vent valves ROV-2307 and ROV-2308 go open.

6) When ROV-225A is open, tank liquid hydrogen valves ROV-2301, 2302, and 2303 will not open. If one of these three valves is open, ROV-225A will not open.

7) If PT1231 (between 2902, 265, and 2105) is below 14.2 PSIA, valves 2902 and 265 cannot be opened.

8) Whenever VP-5 is running, valves SV-3190 (5^{th} floor) and SV-3304 (H24 area) open to supply GHe to purges and vent line. Note: Valve SV-3190 already exists.

9) Valve ROV-2105 cannot be opened when ROV-2107 is open. Valve ROV-2107 cannot be opened if ROV-2105 is open. Note: This is a facility interlock that already exists.

10) Vacuum pump VP-5 shuts down at 1% 02 has measured by the oxygen detector 1270. Note: This is a facility interlock that already exists.

5.6 Alarms

1) PT 2319 alarms if pressure is below 14.2 PSIA.

2) PT 2310 alarms if pressure is above established pressure. This pressure will vary depending upon phase of testing. When the test pressure is 36 PSIG, the alarm will occur at 40 PSIG. When the test pressures are 75 PSIA and 100 PSIG, the alarm will occur at 80 PSIG and 105 PSIG, respectively.

3) GH2 detectors at support structure (2) and in equipment trailer (2) alarm at 0.5% GH2 and 1% GH2.

4) PT 4403, 4404, IA, IB, and 9, alarm on loss of pressure in purged cabinets.

5) There is a 0.5% and 1% 02 alarm associated with the oxygen detector 1270 for VP-5.

6) PS-3311 alarms on loss of GHe purge pressure for the valve box on Dewar H24.

7) PS-3 alarms on loss of GHe purge pressure for flanges exposed to vacuum.

8) PS-2332 alarms on loss of vacuum in the main jacket of Dewar H24.

6. HAZARDS

Included in this section are the individual sheets addressing hazards associated with this test program. The Risk Assessment Matrix is in a 4 x 5 format and its various definitions are provided on the following page. During this Hazards Analysis, none of the Final Risk Assessment Codes are below the level of 12. The areas reviewed and the associated abbreviations are listed below.

1. Liquid Hydrogen Dewar H-24	D-1 through D-8
2. Lockhead Martin Subscale Tank	SCT-1 through SCT-11
3. VP-5 and Low Pressure Vent System	LP-1 through LP-2
4. Tank Support Structure Scaffold System	TSSSS-1 through TSSSS-2
5. Piping Systems	PS-1 through PS-3
6. Gas Detection System and Trailer	GD-1 through GD-10

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 5/8/98	**Hazard Number:** D-1	**Rev.** baseline
System/Component: Liquid Hydrogen Dewar H24		**Final RAC:** 12
System Event or Phase: Actual test		

Hazard Description: LH2 leakage from H24 dewar

Cause of Hazard: Collapse of inner container due to:
1. Pulling vacuum on inner container to reduce temperature of LH2, and
2. Loss of vacuum in annulus between inner container and outer jacket.

Effect on System/Personnel: Release of LH2 into area and subsequent ignition. Destruction of H24 dewar.

Countermeasures:
1. Verify adequate vacuum level in insulation annulus for H24 dewar during checkout phase.
2. Remotely monitor vacuum in insulation annulus during testing. Alarm to be provided in the event that insulation vacuum rises above 1000 microns Hg pressure.

Verifications (Numbers correspond to the Countermeasures above):
1. Vacuum will be verified by approved procedure.
2. Remote vacuum sensor will be installed and verified by work order.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	I	D	8
Final	I	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 5/8/98	**Hazard Number:** D-2	**Rev.** baseline
System/Component: Liquid Hydrogen Dewar H24		**Final RAC:** 12
System Event or Phase: Actual test		

Hazard Description: Leakage of ambient air into inner container of H24 dewar under negative pressure.

Cause of Hazard: Some valves and fittings on dewar H24 are not designed for negative pressure and ambient air could leak through fittings or valve packings into inner container while it is under negative pressure (less than ambient pressure).

Effect on System/Personnel: Entrainment of ambient air into liquid container could cause formation of solid air particles which could:
1. Plug relief devices causing overpressure in inner container.
2. Lodge in system valves and piping preventing valves from opening or closing.
3. Vaporize during warm up of dewar or piping and allow an explosive mixture of oxygen and hydrogen to be present in the system. Ignition of this mixture could cause destruction of dewar H24 and associated facilities.

Countermeasures:
1. Enclose dewar piping cabinet and purge entire area with helium gas.
2. Perform leak check on dewar prior to installation at test site to verify no detectable leaks in piping components.
3. Install pressure switch PS-3311 in piping cabinet to verify at least ½" W.C. pressure of helium gas in piping cabinet.
4. Utilize a source of GHe or GH2 for pressurizing dewar instead of pressure building coil, as PB coil may be a potential source of leaks. Maintain PB coil at above atmospheric pressure at all times.

Verifications (Numbers correspond to the Countermeasures above):
1. Cabinet enclosure & purge will be verified by work order.
2. Leak check on piping will be verified by work order.
3. Pressure switch will be installed per work order and verified by procedure.
4. Verification of pressurization method for dewar will be established by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	I	B	2
Final	I	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 5/8/98	**Hazard Number:** D-3	**Rev.** baseline
System/Component: Liquid Hydrogen Dewar H24		**Final RAC:** 12

System Event or Phase: Actual test

Hazard Description: Leakage of ambient air into inner container of H24 dewar under negative pressure.

Cause of Hazard: Failure of primary relief valve or bursting disks on H24 dewar.

Effect on System/Personnel: Entrainment of ambient air into liquid container could cause formation of solid air particles which could:

1. Plug relief devices causing overpressure in inner container.
2. Lodge in system valves and piping preventing valves from opening or closing.
3. Vaporize during warm up of dewar or piping and allow an explosive mixture of oxygen and hydrogen to be present in the system. Ignition of this mixture could cause destruction of dewar H24 and associated facilities.

Countermeasures:

1. Install new bursting disks in case existing bursting disks have fatigued due to vacuum/pressure cycling of dewar.
2. Verify new bursting disks are provided with vacuum supports.
3. Purge vent stack with helium to minimize possibility of air flowing back to the dewar in the event of a failure.

Verifications (Numbers correspond to the Countermeasures above):

1. Burst disk installation verified by work order.
2. Burst disk vacuum support inclusion verified by work order.
3. Purge verified by procedure - reference pressure transducer 2319.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	I	D	8
Final	I	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS K-SITE		
Date: 4/27/98	**Hazard Number:** D-4	**Rev.**
System/Component: Dewar H24		**Final RAC:** 12
System Event or Phase: Testing or Stand-By		

Hazard Description:
Unable to vent Dewar H24 causes explosion.

Cause of Hazard:
Dewar H24 vent valve V10 is no longer the single vent valve for Dewar. Facility vent valves ROV 265 and ROV 2902 fail to operate.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Two valves provided to eliminate single point failure.
2. Valves ROV 265 and ROV 2902 fail open.
3. Valves cycled and operation verified before testing.
4. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Valves installed per test schematic.
2. Valves verified fail open per Work Order.
3. Valve operation verified by Remote Valve Procedure.
4. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** D-5	**Rev.**
System/Component: Dewar H24		**Final RAC:** 12
System Event or Phase: Post Test		

Hazard Description:
Air/hydrogen mixture causes explosion

Cause of Hazard:
Frozen air warms up after H2 is warmed up. The frozen air could potentially be formed during sub-atmospheric test operations.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Immediately after sub-atmospheric testing, dewar is drained and purged twice with vacuum and GHe. Dewar is then repurged once after it is warmed-up (before next usage).
2. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Purging is performed per approved procedure.
2. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** D-6	**Rev.**
System/Component: LH2 Dewar H24		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
LH2 Dewar H24 damaged from deflagration.

Cause of Hazard:
Deflagration of gas after failure of 10 ft. multi-lobed tank.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Eliminate sources of ignition.
2. Dewar H24 will be at test stand for 10 ft. tank tests with tank pressures below 36 PSIG. For test pressures above this, the dewar will be removed from the site.
3. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. All electrical cabinets purged by procedure.
2. Dewar H24 purged and removed from test site by procedure. Multi-lobe tank has been previously tested to 100 PSIG with LH2 and therefore has factor of safety against failure of 2.78 (100/36) during these tests.
3. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** D-7	**Rev.**
System/Component: H24 Vent		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Vacuum is pulled on vent line of H24 out to burn-off which allows air/hydrogen mixture to form and then explode.

Cause of Hazard:
During vacuum operations, vent valve 2902 and vacuum valve 2105 are left open at the same time.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss (Explosion Destroys Tanks)

Countermeasures:
1. Valve 2105 and vent valves 265 and 2902 are interlocked so that they can not be open at the same time.
2. O2 analyzer is in system (monitoring gas pulled by VP-5)
3. When PT-1231 indicates below 14.7 PSIA, an electrical interlock prevents the opening of vent valves 265 and 2902.
4. PT-2319 and PS-2270 alarm if below 1 ATM.
5. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Interlock to be verified.
2. 02 analyzer set and calibrated by Work Order.
3. Interlock verified by Work Order.
4. Alarms verified by Work Order.
5. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	B	2
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** D-8	**Rev.**
System/Component: H24 Vent		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Air/hydrogen mixture is allowed to form causing explosion.

Cause of Hazard:
During vacuum operations, valve 2902 leaks allowing air to be pulled backwards into vent.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss (Explosion Destroys Tanks)

Countermeasures:
1. A GHe purge is maintained between 2902 and check valve CV-2 by SV3304 to maintain positive pressure in vent whenever VP-5 is on.
2. Pressure transducer PT2319 monitors pressure between 2902 and CV-2. Alarm is triggered for PT if below 1 atm.
3. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Purge established by procedure.
2. Alarm is verified.
3. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/29/98	**Hazard Number:** SCT-1	**Rev.** baseline
System/Component: Lockheed Martin Subscale Tank		**Final RAC:**
System Event or Phase: Actual Test		

Hazard Description: Excessive pressurization of LMST (i.e. test article)

Cause of Hazard: Failure of valve ROV-2304 allowing the excessive pressurization via the LMST pressurization line.

Effect on System/Personnel:
Rupture of test article, with subsequent release of LH2. Death or personnel injury.

Countermeasures:
1. Bursting disk ROV-2309 in vent line will be set at < max. allowable pressure of LMST.
2. Vent valves ROV-2305,2307,2308 available to relieve pressure.
3. Pressurization through ROV-2304 can be stopped by closing valve 2955.
4. Personnel are in control room during testing (outside of exclusion zone – Appendix A)
5. PT-2310 pre-set to close ROV-2304 and open vent valves ROV 2307/2308 at set pressure.

Verifications (Numbers correspond to the Countermeasures above):
1. Verification by inspection.
2. Verification by Remote Valve Procedure.
3. Verification by Remote Valve Procedure.
4. Personnel are in control room by procedure.
5. Verification by Remote Valve Procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	I	D	8
Final	I	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/29/98	**Hazard Number:** SCT-2	**Rev.** baseline
System/Component: Lockheed Martin Subscale Tank		**Final RAC:** 12

System Event or Phase: Actual Test

Hazard Description: Ignition of LH2 within test article.

Cause of Hazard: Lightning strike

Effect on System/Personnel:
Catastrophic release and detonation/deflagration of hydrogen gas released. Death or serious injury to operating personnel in area.

Countermeasures:
1. Test article shall be bonded back to facility lightning protection ground grid.
2. Operating personnel shall be removed from test stand whenever lighting approaches within 5 miles of test site.
3. Testing shall not begin unless an adequate window of opportunity exists for accomplishing test.
4. Test team member shall develop a weather profile prior to start of test. K-Site facility weather radio will be used to determine weather profile. Profile shall be presented at pre-test briefing.
5. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Verification by work order.
2. Verification by procedure.
3. Verification by procedure.
4. Verification by procedure.
5. Personnel are in control room by procedure.

Remarks: Reference appendix A “Explosive Hazard analysis and Siting Lockheed Martin Subscale Tank (LMST) Test Program at Plum Brook K-Site Facility” attached to Preliminary Hazards Analysis.

RISK ASSESSMENT

	Severity	Probability	Code
Initial	I	C	8
Final	I	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS K-SITE		
Date: 4/29/98	**Hazard Number:** SCT-3	**Rev.** baseline
System/Component: Lockheed Martin Subscale Tank		**Final RAC:** 12
System Event or Phase: Actual Test		

Hazard Description: Ignition of LH2 within test article.

Cause of Hazard: Static electricity generated as material in test article tears apart and generates a static charge.

Effect on System/Personnel:
Catastrophic release and detonation/deflagration of hydrogen gas released. Death or serious injury to operating personnel in area.

Countermeasures:
1. Operating personnel shall be removed from test stand during testing.
2. LMMSS personnel shall view LMST strain data real time. No testing shall proceed without verification of allowable strains.
3. If greater than expected leak rates are indicated, testing shall be stopped, and test tank drained and inerted.
4. Test article shall be bonded back to facility lightning protection ground grid.
5. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Verification by procedure.
2. Verification by procedure.
3. Verification by procedure.
4. Verification by procedure.
5. Personnel are in control room by procedure.

Remarks: Reference appendix A "Explosive Hazard analysis and Siting Lockheed Martin Subscale Tank (LMST) Test Program at Plum Brook K-Site Facility" attached to Preliminary Hazards Analysis.

RISK ASSESSMENT

	Severity	Probability	Code
Initial	I	D	8
Final	I	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/29/98	**Hazard Number:** SCT-4	**Rev.** baseline
System/Component: Lockheed Martin Subscale Tank		**Final RAC:** 15

System Event or Phase: Installation

Hazard Description: Damage to tank caused by impact.

Cause of Hazard: Test article struck by extension ladder.

Effect on System/Personnel: Loss of test article and schedule impact to test program.

Countermeasures:
1. Eliminate use of extension ladders around tank by providing fixed ladders to the tank structure.
2. Use of movable scaffolding to work around tank. Scaffolding designed so it will not accidentally strike tank.
3. Train employees working around tank as to proper procedure for moving scaffolding.

Verifications (Numbers correspond to the Countermeasures above):
1. Verification by procedure.
2. Verification by procedure.
3. Verification by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	II	D	10
Final	II	E	15

Engineer	**TSS Manager**	**Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/29/98	**Hazard Number:** SCT-5	**Rev.** baseline
System/Component: Lockheed Martin Subscale Tank		**Final RAC:** 12
System Event or Phase: Installation		

Hazard Description: Damage to tank. Death or injury to personnel.

Cause of Hazard: Lifting operation

Effect on System/Personnel: Loss of test article and schedule impact to test program. Death or serious injury to personnel lifting test article.

Countermeasures:
1. Verify capacity of crane and inspect crane to assure it is in good working order prior to lifting.
2. Develop lifting procedure/plan for conducting lift. Procedure to be developed by LMSS personnel.
3. Assure that only qualified operators operate crane and conduct lifting and placement of test article.
4. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. verification by work order.
2. verification by procedure.
3. verification by procedure.
4. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	I	D	8
Final	I	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 5/8/98	**Hazard Number:** SCT-6	**Rev.** Baseline
System/Component: Lockheed Martin Subscale Tank/B.F.Goodrich Capacitance Gauging Probe		**Final RAC:** 12
System Event or Phase: Actual test		

Hazard Description: Explosion

Cause of Hazard:
Electrical short, open circuits, overvoltage, or excessive current.

Effect on System/Personnel: Damage to facility from fire/explosion. Loss of test article. Death or injury to personnel

Countermeasures:
1. Capacitance Gauge sensor is designed so that any of the above failure mechanisms will not create any ignition potential in an oxygen or oxygen/hydrogen atmosphere. Current flow in any single path is limited to 0.20 ampere under any condition , including malfunction. In addition the temperatures of the sensing elements shall be limited under all operating and malfunction conditions to prevent any ignition source in these atmospheres. The transducer is also designed to prevent catalytic reactions that could cause ignition of these atmospheres.
2. The power supply to the unit will be the as designed unit currently in use by the SSME program.
3. Prior to testing with the probe system powered up, the Test Article should be purged/inerted with helium gas to preclude a fuel/air mixture that is susceptible to ignition.
4. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Verification by review of design, and by work order.
2. Verification by inspection.
3. Verification by procedure.
4. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	I	D	8
Final	I	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** SCT-7	**Rev.**
System/Component: Lockhead Martin Subscale Tank		**Final RAC:** 15
System Event or Phase: Testing		

Hazard Description:
Excessive tank pressure causes tank failure.

Cause of Hazard:
-Failed gas control valve.
-Excessive heat load causes a rapid liquid to gas phase change.

Effect on System/Personnel:
Loss of Equipment (Elimination of Tank)

Countermeasures:
1. Tank is protected with three devices: Burst Disc, Back Pressure Control Valve, and P.S. on tank pressure which controls vent valves.

Verifications (Numbers correspond to the Countermeasures above):
1a. Burst Disc certified by tag. Sized in accordance with CGA.
1b. Back Pressure control valve set by procedure.
1c. Pressure Switch verified by work order.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	11	A	3
Final	11	E	15

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** SCT-8	**Rev.**
System/Component: Lockhead Martin Subscale Tank		**Final RAC:** 12
System Event or Phase: Testing/Clean-Up Operations		

Hazard Description:
Tank is collapsed due to vacuum pulled by VP-5.

Cause of Hazard:
During post test clean-up, vacuum is pulled by VP-5 through the tank drain or fill valves (ROV-2301, 2302, 2303)

Effect on System/Personnel:
Tank Failure

Countermeasures:
1. Interlock valves ROV-2301, 2302, 2303 to be closed when ROV-225A is open.
2. Apply and maintain tank back pressure with pressurant gas.

Verifications (Numbers correspond to the Countermeasures above):
1. Verify interlock by Work Order.
2. Post test clean-up procedure to establish back pressure supply to tank before pulling vacuum on supply lines.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	D	8
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** SCT-9	**Rev.**
System/Component: Lockhead Martin Subscale Tank		**Final RAC:** 12
System Event or Phase: Tank Failure		

Hazard Description:
Hydrogen explosion sending blast wave and fragments towards control room.

Cause of Hazard:
10 Ft. tank ruptures, spilling 3500 gallons of LH2.

Effect on System/Personnel:
Death or Personnel Injury

Countermeasures:
1. Eliminate sources of ignition. Maintain positive pressure on electrical cabinets.
2. During testing, personnel are outside of exclusion zone and in control room (a structure) protected.
3. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Purged cabinets set-up by checksheet and monitored with pressure switch.
2. Based on QD Analysis of LH2 explosions at K-Site date 11-20-92 and Appendix A for the Lockhead Martin Subscale Tank, personnel in control room are outside exclusion zone.
3. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 5/29/98	**Hazard Number:** SCT-10	**Rev.**
System/Component: Test Tank		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Tank explosion due to inability to vent tank.

Cause of Hazard:
Power failure or loss of valve operator.

Effect on System/Personnel:
Death or Personnel Injury/Loss of tank.

Countermeasures:
1. Tank vent line valves fail open both electrically and pneumatically.
2. Tank provided with burst disc sized per CGA.
3. Personnel located in Control Room during testing.
4. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Failed position of vent valves verified by Work Order.
2. Burst disk installation verified by Work Order.
3. Personnel in Control Room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 5/27/98	**Hazard Number:** SCT-11	**Rev.**
System/Component: Pressurant Gas System		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Subatmospheric conditions in 10' tank

Cause of Hazard:
Disturbance of subcooled liquid collapsing ullage

Effect on System/Personnel:
Collapse of 10' tank, fire of explosion. Injury of death

Countermeasures:
1. Install relief system, which functions under both pressure and vacuum conditions with ch.
2. Perform cycle check (visual and limit switch verification) of valves before transferring from storage vessel
3 Design pressurant gas system which supplies gas at a faster rate than the ullage collapses
4 Personnel evacuated from facility prior to introduction of Hydrogen.

Verifications (Numbers correspond to the Countermeasures above):
1. Currently installed and new reliefs verified for proper relieving capacity. Burst disk contains a vacuum backing which will allow it to function under both pressure and vacuum
2.System valve setup and operation verified in the Remote Valve Checksheet prior to test.
3. Ullage collapse data from previous slush testing at K-site was reviewed for 62ft^3, which had similar ullage volume as the 10' tank. The capacity of the pressurant gas system was verified to excede the collapse rate of the 62ft^3 under worst case conditions.
4. Personnel evacuation is part of the Run Day Checksheet.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS K-SITE		
Date: 4/27/98	**Hazard Number:** LP-1	**Rev.**
System/Component: VP-5 and Low Pressure Vent System		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Explosion due to GH2/air mixture in low pressure vent system.

Cause of Hazard:
Air leakage from mechanical joints.

Effect on System/Personnel:
Death or Personnel Injury/Loss of System

Countermeasures:
1. All mechanical joints have either double NASA serrations or aluminum mylar taped joints that are purged with GHe.
2. A 02 meter is installed in the exhaust line of VP-5 to check for oxygen in system. There is an alarm at 0.5% 02 and shutdown at 1% 02.
3. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. GHe system is set-up per checksheet and flow meter at the end of the purge line is verified to have GHe flowing to it.
2. O2 meter is set-up and calibrated per checksheet.
3. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer ________ **TSS Manager** ________ **Safety Office** ________

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** LP-2	**Rev.**
System/Component: VP-5 and Low Pressure Vent System		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Oil in VP-5 becomes cold and shuts down pump.

Cause of Hazard:
Extended vacuum pumping operations with VP-5 on Dewar H24.

Effect on System/Personnel:
Test Delay

Countermeasures:
1. Heat exchanger 2106 maintains gas vapor temperature above 40NF going to VP-5.
2. Electric oil heaters are installed in VP-5.

Verifications (Numbers correspond to the Countermeasures above):
1. Heat exchanger verified operational per Work Order.
2. Oil heaters verified operational per Work Order.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	IV	B	16
Final	IV	E	20

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 5/29/98	**Hazard Number:** TSSSS-1	**Rev.**
System/Component: Tank Support Structure Scaffold System		**Final RAC:** 12
System Event or Phase: Build-Up		

Hazard Description:
Technician steps off scaffold system and falls

Cause of Hazard:
Missing handrail or chain across walkway

Effect on System/Personnel:
Death or Personnel Injury

Countermeasures:
1. Scaffold walkways have handrails on three sides and a safety chain at ladder entrance.
2. All technicians trained on operation of scaffold system.
3. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Scaffold system to be verified by MCG safety office to be within OSHA regulations.
2. Training verified by Work Order.
3. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 5/29/98	**Hazard Number:** TSSSS-2	**Rev.**
System/Component: Tank Support Structure Scaffold System		**Final RAC:** 12
System Event or Phase: Build-Up		

Hazard Description:
Technician falls off scaffold system and falls

Cause of Hazard:
Structural failure of scaffold

Effect on System/Personnel:
Death or Personnel Injury

Countermeasures:
1. Scaffold System, including grating, designed for 750 lb on each side, or 1500 lb total.

Verifications (Numbers correspond to the Countermeasures above):
1. Scaffold System is load tested to 750 lb on each platform or 1500 lb total.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 6/2/98	**Hazard Number:** PS-1	**Rev.**
System/Component: Piping Systems		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Excessive pressure causes piping explosion

Cause of Hazard:
Cryogenic liquid trapped between closed valves

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Relief valves installed between valves and routed to hydrogen vent system.
2. Personnel are in Control Room during testing

Verifications (Numbers correspond to the Countermeasures above):
1. All relief valves verified by Work Order for proper relief pressure identified on PFSK980505.
2. Personnel are in Control Room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 6/2/98	**Hazard Number:** PS-2	**Rev.**
System/Component: Piping Systems		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Liquid Hydrogen Leakage Into Air Causes Explosion

Cause of Hazard:
Liquid hydrogen spill from piping

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. All welds performed by qualified welders
2. All welds leak checked
3. Personnel are in Control Room during testing

Verifications (Numbers correspond to the Countermeasures above):
1. All cold shocked welds and x-rayed by Work Order.
2. Bubble leak check or vacuum leak check performed by Work Order.
3. Personnel are in Control Room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 6/22/98	**Hazard Number:** PS-3	**Rev.**
System/Component: Piping Systems		**Final RAC:** 20
System Event or Phase: Testing		

Hazard Description:
Loose materials in piping lines prevent proper valve closure or restrict operations.

Cause of Hazard:
Loose materials from the 10 ft. Multilobe Tank are moved out of the tank during filling and draining of the tank.

Effect on System/Personnel:
Test Delay

Countermeasures:
1. Install strainers in the supply and drain lines of the Multilobe Tank.
2. Check filters in supply line after the first cold shock with LN2.

Verifications (Numbers correspond to the Countermeasures above):
1. Verification of filters by Work Order.
2. Verification of clean filters by Work Order.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	III	D	14
Final	IV	E	20

Engineer ____________ **TSS Manager** ____________ **Safety Office** ____________

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** GD-1	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Hydrogen gas/air mixture explodes in trailer.

Cause of Hazard:
Hydrogen sensor in trailer not calibrated properly to cause proper alarm/shutdown.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Trailer will include two GH2 Detector Sensors to provide redundancy.
2. Two GH2 detectors at tank support structure provide additional notification of leakage.
3. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. GH2 detectors checked by Work Order with CAL gas for proper setting.
2. GH2 detectors checked by Work Order with CAL gas for proper setting.
3. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	C	4
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 4/27/98	**Hazard Number:** GD-2	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Hydrogen gas/air mixture explodes in trailer.

Cause of Hazard:
Equipment trailer, which is not rated for a Class 1, Group B, Division II installation, is located within the 50ft. separation distance (30 ft. actual) identified by NFPA 5OB-Table 3-2.2 for the permission of open flames and welding (similar to sparking devices)

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Power to trailer systems is shutdown at 1% GH2 and warning is provided at 0.5% GH2 when GH2 is detected by sensors located at either the tank support stand or in the trailer. Tank vent valves are opened.
2. Minimize potential leak sources in trailer and verify a "no acceptable leak condition" for fittings.
3. Personnel are in control room during testing (outside of exclusion zone – see Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Verify power is shutdown and alarms work when triggered by Work Order.
2. Verify no acceptable leak by Work Order.
3. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 5/28/98	**Hazard Number:** GD-3	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Hydrogen gas/air mixture explodes in trailer.

Cause of Hazard:
The power shutdown to the trailer at 1% GH2 is achieved by a shunt trip breaker. The spark generated by the shunt trip breaker causes explosion.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Electrical box in trailer (with shunt trip breaker) is purged with shop air.
2. Personnel are in control room during testing (outside of exclusion zone – see Appendix A)
3. The 1% GH2 shutdown of trailer systems has F.S. of 4 when compared to the LFL which is 4% GH2 in air.

Verifications (Numbers correspond to the Countermeasures above):
1. Pressure in purged boxes is verified by pressure switch. Alarm is verified by W.O.
2. Personnel are in control room by procedure.
3. Verify by W.O. that all power is shutdown to trailer systems (air conditioner, gas detection analyzer and PLC, signal conditioners, hi-cal block, NEFF) at specified GH2 levels.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS K-SITE		
Date: 05/28/98	**Hazard Number:** GD-4	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Hydrogen gas/air mixture explodes in trailer.

Cause of Hazard:
Hydrogen is pulled into the trailer by air conditioner. Equipment in trailer is not rated for Class I, Group B, Division II.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Air conditioner does NOT pull external air into trailer – cools air inside trailer only.
2. Personnel are in control room during testing (outside of exclusion zone – See Appendix A)
3. Power to trailer systems is shutdown at 1% GH2 and warning is provided at 0.5% GH2 when GH2 is detected by sensors located at either the tank support stand or in the trailer.

Verifications (Numbers correspond to the Countermeasures above):
1. Cooling method verified in operating manual of air conditioner
2. Personnel are in control room by procedure.
3. Verify by Work Order that all power is shutdown and alarms work at specified GH2 levels.

Remarks:
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RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer ____________ **TSS Manager** ____________ **Safety Office** ____________

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date 05/28/98	**Hazard Number:** GD-5	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Hydrogen gas/air mixture explodes in trailer.

Cause of Hazard:
Hydrogen gas comes into trailer through open trailer window, trailer door, or other man-made wall opening. Equipment in trailer not rated for Class I, Group B, Div. II.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Windows, doors, and any other openings will be closed before testing.
2. Personnel are in control room during testing (outside of exclusion zone – See Appendix A)
3. Power to trailer systems is shutdown at 1% GH2 and warning is provided at 0.5% GH2 when GH2 is detected by sensors located at either the tank support stand or in the trailer.

Verifications (Numbers correspond to the Countermeasures above):
1. All openings in trailer verified closed by procedure prior to testing.
2. Personnel are in control room by procedure.
3. Verify by Work Order that all power is shutdown and alarms work at specified GH2 levels.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 05/28/98	**Hazard Number:** GD-6	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Hydrogen gas/air mixture explodes in trailer.

Cause of Hazard:
Problem at test stand warrants concern for conditions in trailer.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Manual emergency shutdown of power to equipment trailer is provided in control room.
2. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Operation of manual emergency shutdown switch is verified by Work Order.
2. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS K-SITE		
Date: 05/28/98	**Hazard Number:** GD-7	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Test Build-Up		

Hazard Description:
Asphyxiation of personnel in trailer.

Cause of Hazard:
GN2 from bag purge system fills trailer – displaces oxygen.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Oxygen sensor and alarm are provided for trailer.
2. High flow GN2 lines from multi-lobe tank do not pass through trailer. Only the small flow lines going to gas detection system are routed into trailer.
3. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Calibration of 02 sensor verified by Work Order.
2. Lines verified to be leak free by Work Order.
3. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 05/28/98	**Hazard Number:** GD-8	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Test Build-Up		

Hazard Description:
Asphyxiation of personnel or hydrogen gas/air mixture explodes in trailer.

Cause of Hazard:
High pressure calibration gas k-bottles (GN2 and GH2) leak in trailer.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Calibration gas k-bottles and their regulators are located in secure position outside trailer.
2. GH2 and O2 sensors located in trailer for constant air monitoring.
3. All lines bubble leak checked.
4. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. K-bottles and lines installed per Work Order.
2. Set points and alarms for GH2 and 02 sensors verified by Work Order.
3. Lines verified to be leak free by Work Order.
4. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer **TSS Manager** **Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 05/28/98	**Hazard Number:** GD-9	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Hydrogen gas/air mixture explodes at test stand.

Cause of Hazard:
Bags located on tank rip open allowing hydrogen leaks into air around tank.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Personnel are in control room during testing (outside of exclusion zone – See Appendix A)
2. All sparking devices at test stand are in purged boxes.
3. GH2 detectors at test stand provide warning at 0.5% GH2, and shutdown of power to the trailer combined with tank vent valves opening to relieve pressure at 1% GH2.
4. Pressure transducers located in each bag vent line confirm positive pressure in bags. If this cannot be established, then bag is defective and test must be stopped to allow test clean-up and repair of bag.

Verifications (Numbers correspond to the Countermeasures above):
1. Personnel are in control room by procedure.
2. Purged boxes setup by procedure and verified by alarms from pressure switches.
3. Set points of GH2 detectors, their alarms, power shutdown to trailer, and vent valves opening verified by Work Order.
4. Pressure in bags confirmed in procedure.

Remarks:
The event of bag failure occurred during previous tests at Stennis. However, at no time did the GH2 detectors at the test stand indicate any GH2. This confirms the fast rate of dissipation of GH2 in air and a relatively low leak rate of the tank.

RISK ASSESSMENT

	Severity	Probability	Code
Initial	1	A	1
Final	1	E	12

Engineer	**TSS Manager**	**Safety Office**

PROPELLANT DENSIFICATION HAZARD ANALYSIS
K-SITE

Date: 6/22/98	**Hazard Number:** GD-10	**Rev.**
System/Component: Gas Detection System and Trailer		**Final RAC:** 12
System Event or Phase: Testing		

Hazard Description:
Hydrogen gas/air mixture explodes in trailer.

Cause of Hazard:
Technician operating electrical components during a site entry causes electrical spark.

Effect on System/Personnel:
Death or Personnel Injury/Equipment Loss

Countermeasures:
1. Personnel will enter test site with all systems nominal and the tank in a vented/quiescent state.
2. Personnel are in control room during testing (outside of exclusion zone – Appendix A)

Verifications (Numbers correspond to the Countermeasures above):
1. Personnel enter site using approved Site Entry Procedure.
2. Personnel are in control room by procedure.

Remarks:

RISK ASSESSMENT

	Severity	Probability	Code
Initial	I	D	6
Final	I	E	12

Engineer **TSS Manager** **Safety Office**

Appendix C

Hazards Verifications

(To be completed)